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NON-STANDARD TAU PAIR PRODUCTION IN TWO PHOTON COLLISIONS AT LEP II AND BEYOND [1]

Fernando Cornet and José I. Illana

Depto. de Física Teórica y del Cosmos,

Univ. de Granada, 18071 Granada, Spain

ABSTRACT

We study the sensitivity of LEP II and NLC, via two photon collisions, to the effects of anomalous $\tau\overline{\tau}\gamma$ couplings. We also discuss some CP-odd observables that can be useful to disentangle the contributions from the anomalous couplings.

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The present bounds on the anomalous magnetic and electric dipole moments of the e and μ [1, 2] are much stronger than the ones for the τ [3, 4, 5]. This is particularly unfortunate since larger deviations from the Standard Model values are expected for the τ than for the other leptons. An example is provided by Weinberg-type models [6], where the electric dipole moment is generated via neutral spin 0 bosons coupled to the leptons. The obtained electric dipole moment is proportional to the third power of the lepton mass. In composite models, one would also expect larger effects for the tau than for the rest of the leptons.

The advantages of studying these anomalous couplings in two photon collisions are twofold. First, from the theoretical point of view it is a very clean process, since there is no contribution from the Z boson and the photons are almost real, avoiding any possible, unknown form-factor effects. Second, the measurements are complementary to the ones obtained in other processes, e.g. e^+e^- annihilations. The problem, however, is that very high energy $e^\pm$ beams, compared with the τ mass, are required in order to have an $e^+e^- \to e^+e^-\tau^+\tau^-$ cross-section large enough to allow for a detailed study. But this is just the case for LEP II and more energetic e^+e^- colliders!. A similar analysis for heavy ion colliders has been done in [7]

The most general form of the electromagnetic $\tau\overline{\tau}\gamma$ vertex compatible with Lorentz invariance and hermiticity [8] is given by

$$- ie\overline{u}(p')(F_1(q^2)\gamma^\mu + iF_2(q^2)\sigma^{\mu\nu}\frac{q_\nu}{2m_\tau} + F_3(q^2)\gamma_5\sigma^{\mu\nu}\frac{q_\nu}{2m_\tau})u(p)\epsilon_\mu(q), \tag{1}$$

where $\epsilon_\mu(q)$ is the polarization vector of the photon with momentum q, $F_1(q^2)$ is related to the electric charge, $e_\tau = eF_1(0)$, and $F_{2,3}$ are the form factors related to

the magnetic and electric dipole moments, respectively, through

$$\mu_\tau = \frac{e(1+F_2(0))}{2m_\tau} \quad ; \quad d_\tau = \frac{eF_3(0)}{2m_\tau}. \tag{2}$$

In the Standard Model at tree level, $F_1(q^2) = 1$ and $F_2(q^2) = F_3(q^2) = 0$. It should be noted that the F_2 term behaves under C and P like the Standard Model one, while the F_3 term violates CP.

The most stringent bounds on F_2 and F_3 come from the study of the angular distribution in $e^+e^- \to \tau^+\tau^-$ at PETRA:

$$\begin{aligned} |F_2| &\leq 0.014 \quad [3] \\ |F_3| &\leq 0.025 \quad [4] \end{aligned} \tag{3}$$

These bounds, however, neglect the effects of the form factors from $q^2 = 0$ to $\sim 1.5 \times 10^3\ GeV^2$, where the measurents were taken. A way to avoid this problem at LEP was proposed in Ref. [9]. Instead of looking at deviations from the Standard Model in tau pair production, one should study $e^+e^- \to \tau^+\tau^-\gamma$. Using this method the bound obtained is [5]

$$|F_2(0)|\ ,\ |F_3(0)| \leq 0.23. \tag{4}$$

The inclusion of the new terms in Eq. 1 leads to unitarity violations leading to an enhancement in the cross-section for large τ-pair invariant masses. However, due to the effective $\gamma\gamma$ luminosity, the cross-sections in the Standard Model and for reasonably small values of F_2 and F_3 are dominated by the production of τ-pairs with low invariant masses (this is shown for the Standard Model at LEP II in

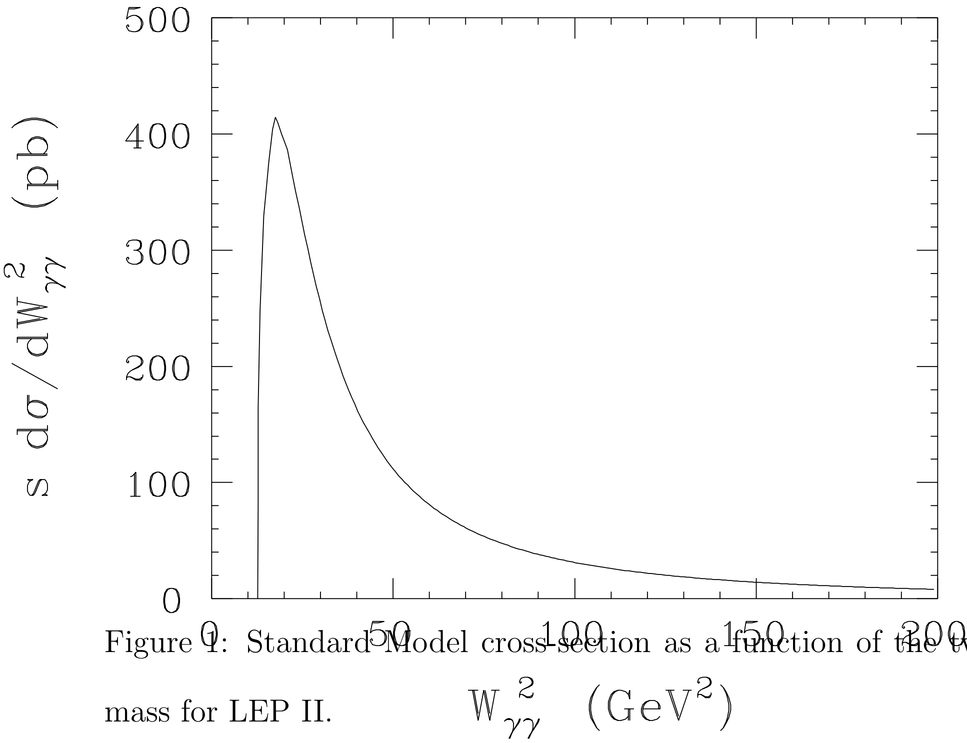

Figure 1: Standard Model cross-section as a function of the two photon invariant mass for LEP II.

Fig. 1). We can, thus, neglect the effects introduced by the unknown unitarization procedure.

The Standard Model total cross-sections are $0.47\ pb$ at LEP II and $0.792\ pb$ at NLC. Assuming the integrated luminosities to be $500\ pb^{-1}$ and $10\ fb^{-1}$ one expects a total amount of 235 and 7920 τ-pairs, respectively. In Figs. 2 and 3 we show the dependence of the total cross-section with F_2 for LEP II and NLC, respectively. Since the relevant values of F_2 are small, the dependence of the cross-section on F_2 can be considered as linear with a very good approximation:

$$
\begin{aligned}
\sigma &= (0.47 + 1.55 F_2)\ pb \qquad \text{LEP II} \\
\sigma &= (0.792 + 2.167 F_2)\ pb \qquad \text{NLC.}
\end{aligned}
\tag{5}
$$

This approximation is extremely good for NLC and better than a 4% for LEP II in the range of F_2 values covered in the figures. The Standard Model cross-section is obtained for $F_2 = 0$ and the expected statistical errors for the assumed luminosities are shown with the dash lines. In this way we see that the bounds $F_2 \leq 0.021$ and 0.004 can be obtained at LEP II and NLC, respectively. These bounds, however, have been obtained assuming that all the produced τ-pairs will be identified. This is certainly too an optimistic assumption. We can exploit the simple behavior of the cross-section with respect to F_2, Eqs. 5, to express the achievable bounds in terms of the luminosity and detection efficiency:

$$
\begin{aligned}
F_2 &\leq \frac{0.442 \text{ pb}^{-1/2}}{\sqrt{L\epsilon}} \qquad \text{LEP II} \\
F_2 &\leq \frac{0.410 \text{ pb}^{-1/2}}{\sqrt{L\epsilon}} \qquad \text{NLC,}
\end{aligned}
\tag{6}
$$

where ϵ is the fraction of identified τ-pairs and L is the integrated luminosity expressed in inverse picobarns. Assuming the nominal luminosity and a more realistic situation, where 25% of the τ-pairs are identified, one gets $F_2 \leq 0.04$ and ≤ 0.008 from LEP II and NLC, respectively. Comparing with Eq. 3 it is clear that the bounds that can be obtained at NLC are much more stringent than the present ones. At LEP II, however, one can certainly improve the bounds obtained at LEP, but not the ones from PETRA, although one should remember here that they are obtained at different values of q^2.

The dependence of the cross-section with F_3 is shown in Figs. 4 and 5. Due to the CP-violating nature of this term, the interference with the Standard Model cancels and the dominant correction becomes $O(F_3^2)$. The sensitivity to the

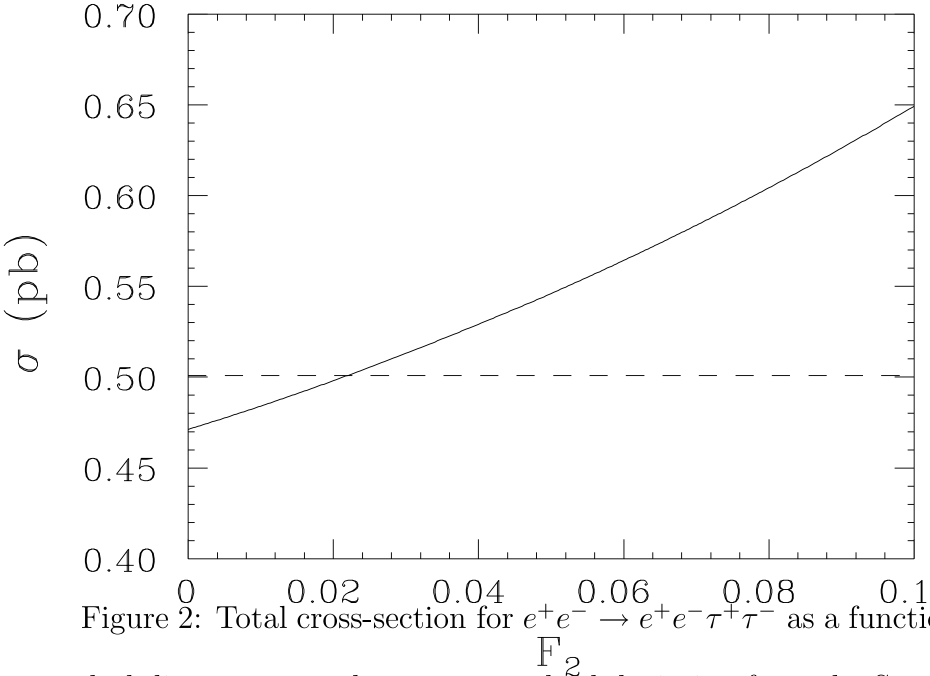

Figure 2: Total cross-section for $e^+e^- \to e^+e^-\tau^+\tau^-$ as a function F_2 at LEP II. The dash line corresponds to one standard deviation from the Standard Model value.

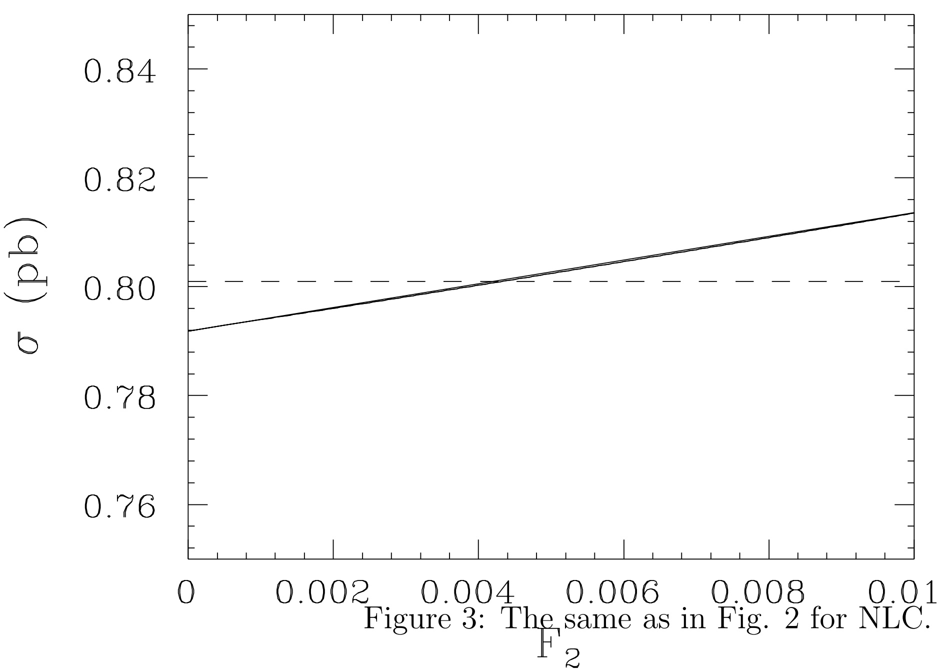

Figure 3: The same as in Fig. 2 for NLC.

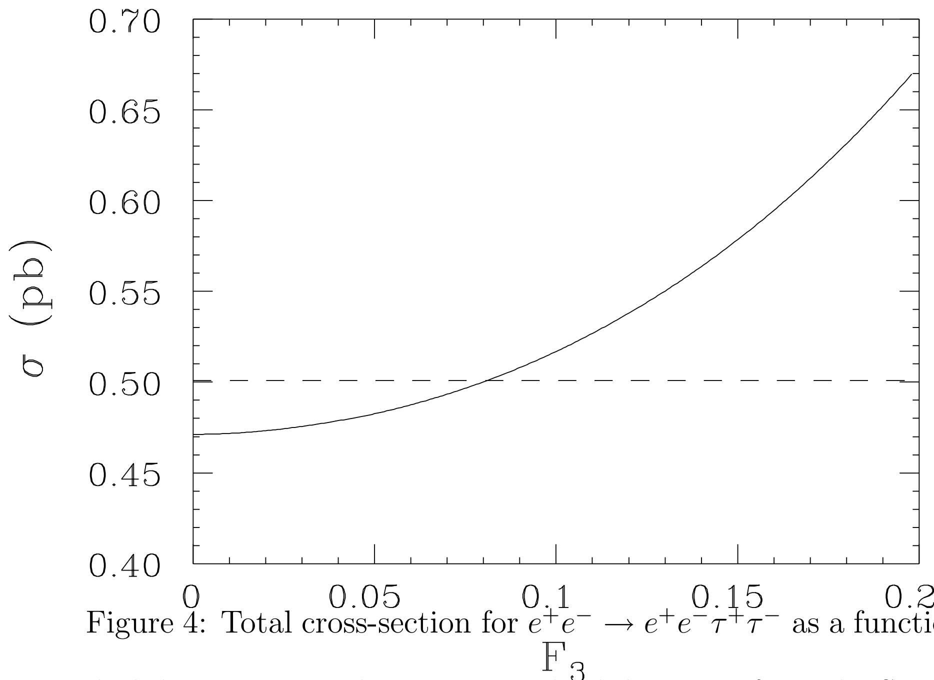

Figure 4: Total cross-section for $e^+e^- \to e^+e^-\tau^+\tau^-$ as a function F_3 at LEP II. The dash line corresponds to one standard deviation from the Standard Model value.

new parameter will, thus, be weaker than in the case of F_2. Assuming that all the produced τ-pairs are identified, we obtain, from Figs. 4 and 5, $F_3 \leq 0.08$ and 0.03 for LEP II and NLC. We can again obtain simple expressions for the bounds in terms of the luminosity and the detection efficiency:

$$\begin{aligned} F_3^2 &\leq \frac{0.151 \text{ pb}^{-1/2}}{\sqrt{L\epsilon}} \qquad \text{LEP II} \\ F_3^2 &\leq \frac{0.093 \text{ pb}^{-1/2}}{\sqrt{L\epsilon}} \qquad \text{NLC,} \end{aligned} \tag{7}$$

The bounds in Eqs. 6, 7 are obtained from the study of deviations in the total cross-section from the Standard Model prediction. One could think that, similar to what it has been done at PETRA, a study of the angular distribution would allow an improvement on the above bounds. However, since the cross-section is dominated

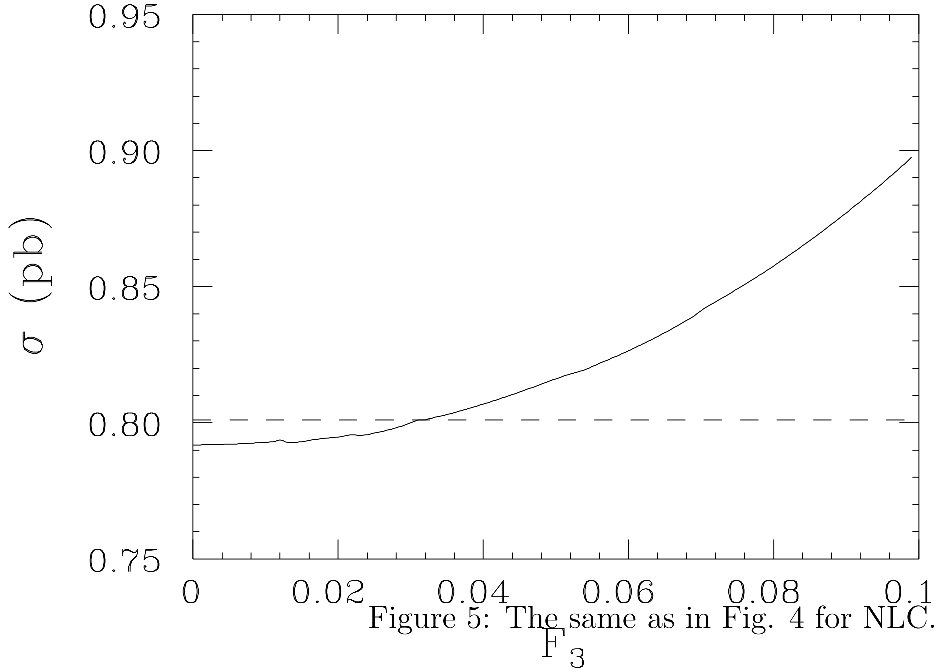

Figure 5: The same as in Fig. 4 for NLC.

by low τ-pair invariant masses this is not the case for F_2. In the case of F_3 there is a small excess of τ's produced at large angles. This effect is not large enough to allow a sensible improvement on the previous bounds.

We have been discussing effects of the order of a few per cent in the total cross-section. This is of the same order as the error introduced in the calculation when using the Weiszäcker-Williams approximation. So, when comparing with real data the theoretical predictions for the whole $e^+e^- \to e^+e^-\tau^+\tau^-$ process should be used. An alternative would be to normalize to the μ-pair production, where the same error in the Weiszäcker-Williams approximation is made.

The bounds we have obtained for F_3 are weaker than the corresponding ones for F_2. We can try to improve these bounds exploiting the CP-violating nature of this term. We have to look for CP-odd observables that cancel in the Standard

Model and the F_2 term and, thus, isolate the terms proportional to odd powers of F_3. We do not attempt a detailed study of these CP-odd observables, rather we are going to discuss only one of them as a showcase. The asymmetry between the cross-sections for polarized τ and $\overline{\tau}$ production:

$$A = \frac{\sigma(s_1, s_2) - \sigma(s_2, s_1)}{\sigma(s_1, s_2) + \sigma(s_2, s_1)}, \tag{8}$$

where the first spin is the one of the τ and the second the one of the $\overline{\tau}$, has the required behavior under CP. We have, as an example, taken s_1 and s_2 in the two perpendicular directions to the τ flight direction in the respective τ or $\overline{\tau}$ rest frame. From this asymmetry one can find the bounds $F_3 \leq 0.05$ and 0.008 for LEP II and NLC, respectively, assuming a total efficiency in the detection of the polarized τ-pairs. In terms of the luminosity and the efficiency, we have:

$$\begin{aligned} F_3 &\leq \frac{1.08 \text{ pb}^{-1/2}}{\sqrt{L\epsilon}} \qquad \text{LEP II} \\ F_3 &\leq \frac{0.83 \text{ pb}^{-1/2}}{\sqrt{L\epsilon}} \qquad \text{NLC.} \end{aligned} \tag{9}$$

It is interesting to note that the value of the asymmetry is almost the same for LEP II and NLC. The larger sensitivity at NLC is basically due to the better luminosity that allows a better determination of the asymmetry.

We have discussed the possibilty of studying the anomalous electromagnetic couplings of the τ at LEP II and NLC in $\gamma\gamma$ collisions. The main effects of the F_2 term appear in deviations of the total cross-section from the Standard Model predictions. The bounds obtained at LEP can certainly be improved at LEP II, but not the ones from PETRA. These bounds can only be improved in a sensitive way at

NLC. With respect to the F_3 term, the sensitivity is much weaker in both colliders and one should perform more elaborated studies, such as CP-odd observables, in order to improve the present bounds from PETRA.

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